Chapter 6

Steel Piers

Resistance Pier Design Examples

- **Calculate Foundation Load – Two Story Residence**
- **Calculate Maximum Pier Spacing for Design Example 1**
- **Adjusting for Pier Buckling in Weak Soil**
- **Determine Foundation Load – Single Story Slab on Grade**
- **Determining Maximum Pier Spacing**
- **Calculate the Foundation Load and Determine Pier Spacing – Three Story Office Building**
- **Estimating Drive Cylinder and Lifting Ram Pressures**
- **Determining Force Applied to Pier**

Design Example 1 – Calculate Foundation Load

Two Story Brick with Full Basement

- The foundation consists of a 12” tall x 24” wide reinforced footing with a 10” thick x 8’-0” tall cast concrete basement wall. (footing toe = 7”)
- The house is located in Indiana with 30+ inches of snow.
- The basement floor is 4” thick concrete.
- The soil depth to the basement floor elevation is 7 feet.
- The upper floors consist of 2 x 8 joists spaced 12” on center that span 12 feet to a steel beam supported by columns. The floors are carpeted.
- The house is 40’ long x 24’ wide with 2 x 4 studs on 16” centers, sheathing, insulation and drywall and brick veneer.
- The hip roof is framed with 2 x 8 rafters and 2 x 6 ceiling joists with a 3” in 12” pitch. There is no attic storage. There is 10” of blown insulation. The ceiling span is 12 feet plus a one foot roof overhang.

Calculate the Foundation Loads - Referring to the Load Tables in Chapter 6 estimate the foundation service (working) load, the live load and the temporary soil load.

1. **Dead Load** (DL):

Footing	=	288 lb/ lin. ft (Table 2)
Stem Wall	=	960 lb/ lin. ft (Table 3)
Slab	=	191 lb/ lin. ft (Table 4)
1st Floor	=	84 lb/ lin. ft (Table 4)
1st Exterior Wall	=	390 lb/ lin. ft (Table 5)
2nd Floor	=	84 lb/ lin. ft (Table 4)
2nd Exterior Wall	=	390 lb/ lin. ft (Table 5)
Roof & Ceiling	=	145 lb/ lin. ft (Table 6)
Perm. Soil Load	=	384 lb/ lin. ft [64# x 7” Toe] (Table 8)
Dead Load (DL)	**=**	**2,916 lb. per lineal foot**

2. **Live Loads** (LL):

Live Load	=	540 lb/ lin. ft (240+180+120) = 540 (Table 7)
Snow Load	=	150 lb/ lin. ft [(40x24)/2(40+24)] x (20#/sf) (Table 9)

Live Load (LL) = **690 lb. per lineal foot**

3. **Working Load** (P_w) = Dead Load + Live Load
Working Load (P_w) = 2,916 lb/lin. ft + 690 lb/lin. ft
Working Load (P_w) = 3,606 lb. per lineal foot

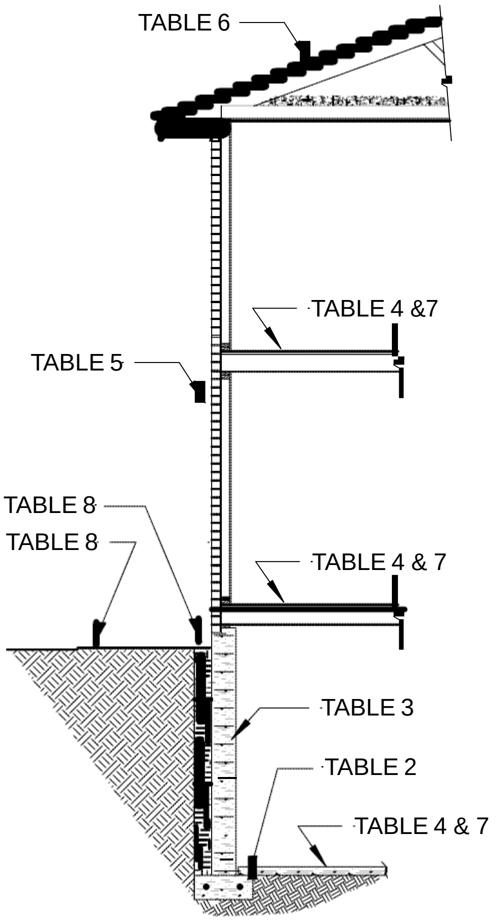


Figure 6. Load Estimate Sketch Example 1 & 1A.

4. **Lifting Load** (P_L) = Working Load + Temporary Soil Load
Temp. Soil Load = 3,606 lb/lin. ft + 2,950 lb/lin. ft (Table 8-Graph 1 & reproduced below)
Lifting Load (P_L) = **6,556 lb. per lineal foot** (See Note Pg 97)

5. **Factored Lifting Load** (P_{LF}) – The factored lifting load adds a percentage to the calculation to help compensate for possible omissions in the weight calculations, unexpected structural elements and the initial force to break the footing away from the surrounding soil. Depending upon confidence 10% to 20% is usually added.
Factored Lifting Load (P_{LF}) = Lifting Load (P_L) + F.S. = 6,556 lb/lin. ft + 656 lb/lin.ft (10% F.S. Uncertainty)
Factored Lifting Load (P_{LF}) = 7,212 lb. per lineal foot **(Use 7,200 pounds per lineal foot)**

END DESIGN EXAMPLE 1

Design Example 1A – Calculate Foundation Load – "Quick and Rough" Method

Two Story Brick with Full Basement

- The house is 40' long x 24' wide with an 8'-0" tall cast concrete basement wall.
- The house is located in Indiana with 30+ inches of snow.
- The basement floor is concrete.
- The soil depth at the basement is 7 feet.

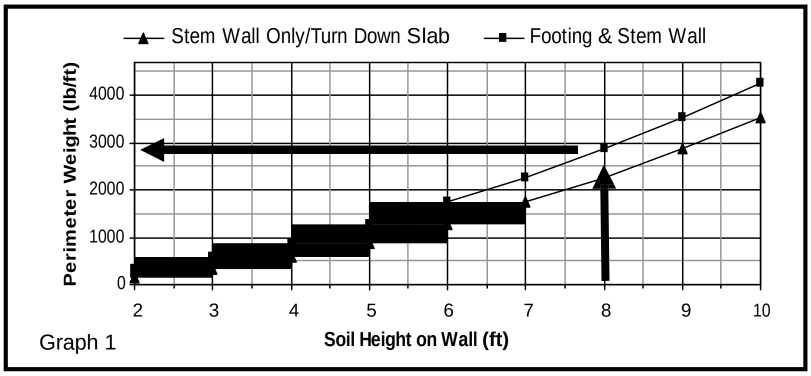
TABLE 10. Ranges for Typical Average Residential Building Loads*	
Building Construction (Basement or Crawlspace & Footing)	Estimated Foundation Load Range (DL = Dead – LL = Live)
One Story Wood/Metal/Vinyl Walls with Wood Framing on Basement or Crawlspace and Footing	DL 1,250 – 1,500 lb/ft LL 300 – 475 lb/ft
One Story Masonry Walls with Wood Framing on Basement or Crawlspace and Footing	DL 1,500 – 2,000 lb/ft LL 300 – 475 lb/ft
Two Story Wood/Metal/Vinyl Walls with Wood Framing on Basement or Crawlspace and Footing	DL 1,400 – 1,900 lb/ft LL 600 – 950 lb/ft
Two Story 1st Masonry, 2nd Wood/Metal/Vinyl – Wood Framing, Basement or Crawlspace & Footing	DL 1,650 – 2,200 lb/ft LL 600 – 950 lb/ft
Two Story Masonry Walls with Wood Framing on Basement or Crawlspace and Footing	**DL 1,900 – 2,500 lb/ft LL 600 – 950 lb/ft**

1. **Estimate the Dead Load and Live Load on the footing:**
   A. Using Table 10 from Chapter 5, select the column that most closely identifies the foundation construction. In this case the third column is selected because the house has a basement with a concrete slab floor.
   B. Second, determine which of the five rows most closely describes the structure. In this case the closest match is the lowest row. (shaded) The construction of the house consists of two story framed construction with brick veneer siding.
   C. The Dead Load for a typical two story house of this description ranges from 1,900 to 2,500 lb/lin.ft and the Live Load averages between 600 and 950 lb/lin.ft. Based upon viewing the house and how robust is the construction and amount of contents, load selections are chosen within the ranges given.
   D. The Snow Load is estimated at <u>150 lb/ lin. ft</u> [(40'x24')/2(40+24')] x (20#/sf) (Chapter 5, Table 9)

   Dead Load (DL) = 2,200 lb/lin.ft (selected) **Live Load (LL) = 750** lb/lin.ft (selected) **Snow Load 150** lb/lin.ft

2. **Estimate the Temporary Soil Load on the footing:**

   The Temporary Soil Load may be estimated using Graph 1 presented in Chapter 5, shown here. The graph line that represents "Footing & Stem Wall" construction is selected because the footing construction is unknown. The Temporary Soil Load can be estimated by reading upward from a soil height of 8 feet (7' of soil on the basement wall + 1' for soil height against the side of the footing.) **Temporary Soil Load = 2,950 lb, lin.ft**



Graph 1

3. **Factored Lifting Load (P_{LF}) = Dead Load + Live Load + Soil Load + Soil Load + Uncertainty Factor**

   Factored Lifting Load (P_{LF}) = 2,200 + 750 +150 + 2,950 lb/ft = **6.050 lb/ft** + 908 lb/lf (F.S. uncertainty: 15%)

   Factored Lifting Load (P_{LF}) = 6,958 per lineal foot **(Use <u>7,000 pounds per lineal foot</u>)**

END DESIGN EXAMPLE 1A

Review of Results of Design Examples 1 & 1A

One can see that the result obtained by the "Quick and Rough" analysis underestimated the foundation load by 3% compared to the more thorough weight analysis. Caution must be taken when using the "Quick and Rough" method because the load estimates are based upon where the designer <u>believes the structural weight falls within the ranges provided</u>. Choices made in this example were in the "middle range". It is quite evident that this structure is more robust than average construction, and loads should have been chosen nearer the higher end of the ranges and/or the Factor of Uncertainty increased.

Design Example 2 -- Calculate the Maximum Pier Spacing for Design Example 1

- An inspection of the property suggests that the structure is well built and the foundation appears sound.
- A "Safe Use" Design Load of 43,000 pounds is selected with the use of the PPB-350 Steel Pier™. This represents a strong and economical pier for this project. (Table 1 – Chapter 5)
- A Factor of Safety of 2:1 is used.
- According to the analysis in Example 1 the structure requires a factored lifting force of 7,300 pounds per lineal foot of perimeter beam.

Equation 1 from Chapter 5 is used to determine the pier spacing relative to pier capacity.

Pier Spacing - "X" = $P_{SU\ Des}/P_L$ (Equation 1)

Where:

"X" = Pier Spacing (ft)

$P_{SU\ Des}$ = "Recommended Design Service Load" (Table 1 – Chapter 5) = 43,000 lbs

P_L = Estimated Lifting Load = 7,300 lb/lin.ft

"X" = 43,000 lb / 7,300 lb/ft (6,600 lb + 10%)

"X" = 5.9 feet

Use **"X" = 6 feet,** (maximum)

The pier placement design may now be prepared and a pricing estimate for this project is possible with piers spaced <u>not to exceed 6 feet on center</u>.

END DESIGN EXAMPLE 2

Design Example 2A – Adjusting for Pier Buckling in Weak Soil

- When discussing this project with the engineer, he mentions that consolidation of a layer of weak soil caused the settlement. Upon further investigations of the soil data, it is learned that there is approximately six feet of uncompacted loose fill with Standard Penetration Test values, "N" = 1 to 3 blows per foot.
- Below six feet, the soil is firm clay with SPT values exceeding "N" = 5 blows per foot.
- According to the analysis in Example 1 the structure requires a factored lifting force of 7,300 pounds per lineal foot of perimeter beam.

First Method: There are two ways to approach this new information. The first is to account for the reduction in pier pipe capacity and adjust the spacing accordingly.

In Example 2 it was determined that the Model 350 ECP Steel Pier™ installed at 6 feet on center would provide full foundation support with a factor of safety of 2:1.

1. **Determine the *Working Load Under Buckling Conditions* for PPB-350 Steel Pier™:**

Table 13, Chapter 5 shows that the Critical Buckling of the pier pipe for a PPB-350 in clay with SPT > 1 is 30,000 pounds, not the *Recomended Design/Service Load* shown in Table 1 in Chapter 5 = 43,000 pounds.

2. **Calculate New Pier Spacing, "X":**

"X" = $P_{SU\ Des}/P_L$ (Equation 1)

X" = 30,000 lb / 7,300 lb/ft = 4.11 ft

Use **<u>"X" = 4 feet</u>,** (maximum)

Second Method: Choose a new product configuration that offers a more rigid pier section and maintain the original pier placement spacing.

1. **Find a Pier Configuration with a *Working Load Under Buckling Conditions* over 43,000 lb:**

Table 13 from Chapter 5 reveals that the *Critical Buckling Loads* for all pier configurations. Notice that using a PPB-350-SB External Sleeve will provide working load capacity that is in excess of 43,000 lb.

Table 13 Working Loads Under Buckling Conditions For Budgetary Estimating (Factor of Safety = 2)

Shaft Size	Uniform Soil Condition: Organics N < 1	Uniform Soil Condition: Very Soft Clay N = 1 - 2
PPB-300-EPS (2-7/8" dia.)	19,000 lb	22,000 lb
PPB-300-EPS + PPB-300-IP	23,000 lb	27,000 lb
PPB-350-EPS (3-1/2" dia.)	26,000 lb	30,000 lb
PPB-400-EPS (4" dia.)	34,000 lb	40,000 lb
PPB-350-EPS + PPB-350-IP	36,000 lb	42,000 lb
PPB-350-EPS + PPB-350-SB	50,000 lb	58,000 lb
3-1/2" + Inert. Slv. + 4" Slv	*99,000 lb*	66,000 lb

2. **Specify the new pier pipe configuration:**

<u>Using the original placement spacing of 6 feet on center</u>, the PPB-350-EPS Steel Pier™ shall be installed along with three sections of PPB-350-SB by 42 inches long external sleeve over the upper 10-1/2 feet of pier pipe. The three pieces PPB-350-SB sleeve shall be installed after the pier pipe has been installed to bearing, but prior to proof testing. Three sections of sleeve will reinforce the pier pipe through a distance of 10-1/2 feet (Minimum length needed is 6 ft + 3 ft into competent soil = 9 ft). The depth from the surface extends more than three feet beyond the depth of the weak fill soil.

END DESIGN EXAMPLE 2A

Design Example 3 – Calculate Foundation Load

Single Story Slab on Grade

- The single story house is located in southern New Mexico
- The foundation consists of an 18" tall x 15" wide turned down footing reinforced with #4 rebars.
- The concrete slab floor is 4" thick and is carpeted.
- The exterior walls are 2 x 4 studs on 16" centers with sheathing, insulation and drywall. The exterior is typical brick veneer,
- The roof has a 3" in 12" pitch and is framed with 2 x 8 rafters and 2 x 6 ceiling joists. There is no attic storage, but there is 10" of blown in insulation. The span is 12 feet with a 2 foot overhang.

Calculate the Foundation Loads - Referring to the Load Tables in Chapter 5, estimate the foundation service (working) load, the live load and the temporary soil load.

1. **Dead Load** (DL):
   Footing = 270 lb./lineal foot (Table 2)
   Slab = 195 lb/ lin. ft (Table 4)
   Exterior Wall = 390 lb/ lin. ft (Table 5)
   Roof & Ceiling = 166 lb/ft (12' + 2' = 14') (Table 6)
   Perm. Soil Load = 0 lb/ lin. ft
   Dead Load (DL) = 1,021 lb. per lineal foot

2. **Live Loads** (LL):
   Live Load = 120 lb/ lin. ft (Table 7)
   Snow Load = 0 lb/ lin. ft
   Live Load (LL) = **120 lb. per lineal foot**

3. **Working Load** (P_w) = Dead Load + Live Load
   Working Load (P_w) = 1,021 lb/lin ft + 120 lb/lin ft
   Working Load (P_w) = 1,141 lb. per lineal foot

4. **Lifting Load** (P_L) = Working Load + Temporary Soil Load

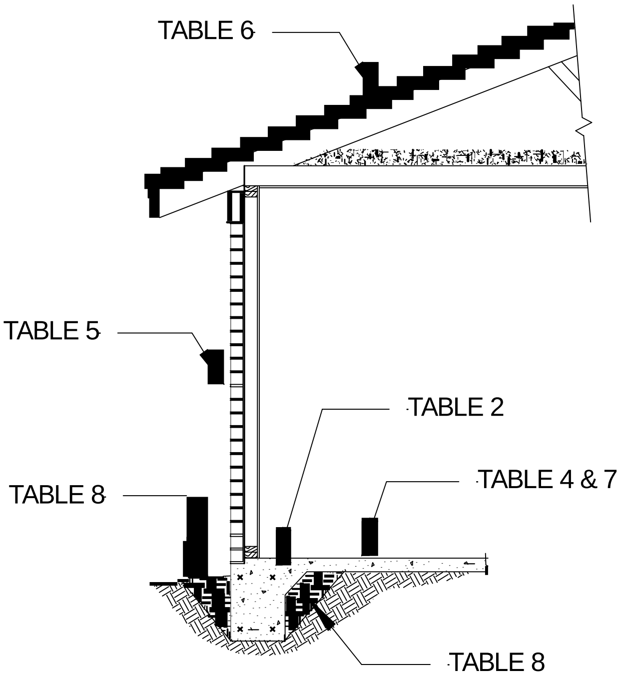


Figure 7. Sketch for Load Estimate Example 3 & 3A.

Temp. Soil Load = 80 lb/lin. ft x 2 (inside and outside turn down) (Table 8 – Graph 1 – estimate because graph does not go as low as 18 inches.)
Temp. Soil Load = **160 lb/lin.ft**

Lifting Load (P_L) = **1,141 + 160 lb. per lineal foot**
Lifting Load (P_L) = **1,301 lb/lin.ft** (See Note Pg 129)

5. **Factored Lifting Load** (P_{LF}) = (P_L) + F.S.
   (P_{LF}) = 1,301 lb/lin,ft + 130 lb/lin.ft = 1,431 lb/ lin.ft
   F.S. uncertainty: 10% "Safe Use" Design
   Factored Lifting Load (P_{LF}) = 1,431 lb/lin.ft.
   (Use 1,450 lb/lin. ft)

END DESIGN EXAMPLE 3

Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to design using ECP Steel Piers™, installation procedures, load testing, and documentation of each pier placement. If you have questions about structural weights, product selection or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call us at 913 393-0007, Fax at 913 393-0008.

Design Example 3A – Calculate Foundation Load – "Quick and Rough" Method

Single Story Slab on Grade

1. Estimate footing Dead Load and Live Load:

A. Using Table 10 from Chapter 5 select the column that most closely identifies the foundation construction. (A portion of Table 10 is reproduced to the right.) In this case the first column is selected because the house has a slab on grade.

B. Second, determine which of the five rows most closely describes the structure. In this case the closest match is the second row. The construction of the house consists of single story framed construction with brick veneer siding.

C. The Dead Load for a typical single story house of this description ranges from 1,000 to 1,200 lb/lin.ft and the Live Load averages between 100 and 200 lb/lin.ft. Based upon viewing the quality of the construction and amount of contents, load values are chosen within these load ranges.

Dead Load (DL) = 1,100 lb/lin.ft (selected)

Live Load (LL) = 150 lb/lin.ft (selected)

Temporary Soil Load is estimated at 80 lb/lin.ft inside and 80 lb/lin.ft outside of the turn down. Graph 1 in Table 8 was presented in Chapter 5. (A small version of Graph 1 was reproduced in Design Example 1A. One must estimate the temporary soil load value because the graph does not go as low as 18 inches.

Table 10. Ranges for Typical Average Residential Building Loads*

Building Construction (Slab On Grade)	Estimated Foundation Load Range (DL = Dead – LL = Live)
One Story Wood/Metal/Vinyl Walls with Wood Framing -- Footing with Slab	DL 750 – 850 lb/ft LL 100 – 200 lb/ft
One Story Masonry Walls with Wood Framing – Footing with Slab	**DL 1,000 – 1,200 lb/ft** **LL 100 – 200 lb/ft**

Temporary Soil Load = 160 lb/lin.ft (estimated)

2. **Estimated Lifting Load** (P_L)
   P_L = Dead Load + Live Load + Soil Load
   P_L = 1,100 + 150 + 160 = **1,410 lb/lin.ft**

3. **Factored Lifting Load** (P_{LF}) = (P_L) + F.S.
   Factor of Safety = 10% "Safe Use" design
   (Structural loads were guessed from Table 10)
   (P_{LF}) = **1,410 + 141 lb/lin.ft** (15%) = **<u>1,551 lb/lin.ft</u>**

END DESIGN EXAMPLE 3A

Review of Results of Design Examples 3 & 3A

The result obtained by the "Quick and Rough" analysis on Design Example 3A overestimated the foundation load by 7% when compared to the more thorough weight analysis. Once again the caution must taken when using the "Quick and Rough" method to select a load estimates. The values selected are based upon the designer's best estimate of where the actual structural weight falls within the ranges provided by the "Quick and Rough" Table 10. It must be kept in mind that the use of the "Quick and Rough" method returns estimates that can vary depending upon where the loads are selected within the ranges. With the "Quick and Rough" method providing a conservative estimate and the difference between the two methods of 100 lb/ft, one can see that the different results do not significantly affect foundation load estimate and ultimately the pier spacing. The "Quick and Rough" method has quickly returned a conservative and useful result.

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Design Example 4 – Calculate the Maximum Pier Spacing for Design Example 3

Because the structure in Example 3 has only a small footing with very light loads, the **foundation strength will limit the pier spacing**. The result of Example 3 suggested a line load of 1,450 lb/ft and Example 3A returned a load estimate of 1,551 lb/ft. For this example 1,500 lb/ft will be used.

To estimate the maximum spacing for pier placement, the lower portion of Graph 2 in Chapter 5 is used. A portion of Graph 2 is shown below. Referring to Graph 2 from Chapter 5, locate the line for an 18" tall monolithic footing in lowest graph and find the load line representing 1,500 lb/ft. Read downward to see the recommended maximum center-to-center pier spacing. It is slightly over seven feet, which will load the reinforcing steel in the concrete to yield strength.

Prepare the preliminary design with a "safe" distance between placements.

Specify **"X" = 7 feet** (MAXIMUM)

The estimated pier load can now be calculated, and an ECP Steel Pier™ is selected for the project.

$\mathbf{P}_{SU\ Des}$ = ("**X**") x $\mathbf{P}_L$ (Chapter 5 - Equation 1),

Where;

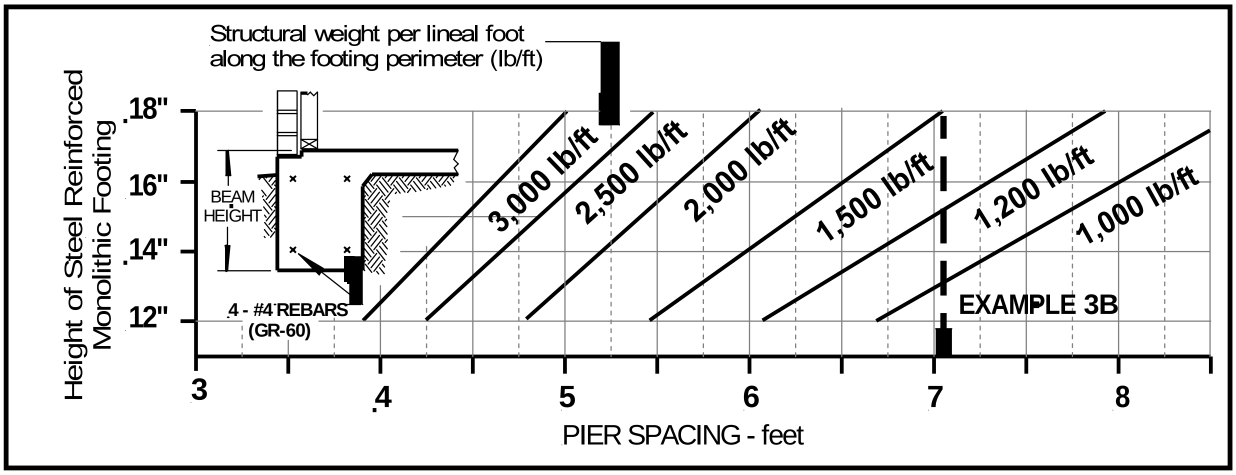
$\mathbf{P}_L$ = Lifting Load = 1,500 lb/lf

X = Pier spacing, feet

$\mathbf{P}_{SU\ Des}$ = **7** ft x **1,500** lb/ft = **10,500 lb**

The ECP Steel Pier™ PPB-300 is selected and when installed at a pier spacing of 7 feet, the piers enjoy a Factor of Safety rating of 6.5:1.

END DESIGN EXAMPLE 4



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Design Example 5 – Calculate the Foundation Load and Determine Pier Spacing

Three Story Office Building

- The three story structure has settled toward the corner. The largest elevation loss was measured at 1-1/2 inches. The engineer requested a pier design and placement proposal based on a steel pier system to support and restore the structure.
- The engineer specified a factor of safety of at least 2.0.
- The foundation consists of an 18" tall x 28" wide reinforced footing with a 10" thick x 3'-0" tall cast concrete stem wall. (Footing toe = 8") The first floor slab is 6" thick concrete.
- The upper floors are constructed of light weight concrete and the roof consists of multi-layer tar and gravel over an insulated metal roof deck.
- The exterior walls are 30 feet tall and consist of heavy weight concrete blocks that are filled and reinforced. The outer surface has a 1-1/2 inch thick simulated stucco covering. Inside the walls consist of steel studs, insulation, and pre-finished drywall.
- The engineer has calculated the dead load at 7,000 lb/lf on the heavy, load bearing side and 4,700 lb/lf on the adjacent wall. The live loads are estimated at 2,600 lb/lf and 1,800 lb/lf respectfully.

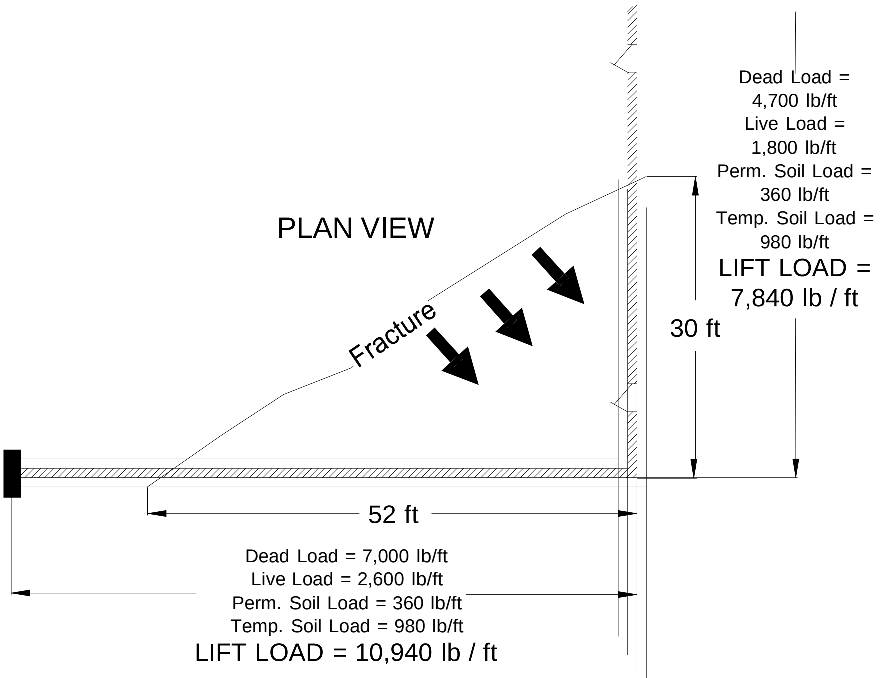


Figure 8. Sketch for Example 5.

1. Determine the Engineer's Working Loads:

Working Load (P_W) = Dead Load + Live Load

Side 1 - $P_{W\,1}$ = 7,000 + 2,600 = 9,600 lb/lf

Side 2 - $P_{W\,2}$ = 4,700 + 1,800 = 6,500 lb/lf

2. Adjust the Working Loads due to Soil Loads:

Reading through the information provided it was noticed that the engineer did not mention a temporary soil load in his working load calculations. A review of Table 8 presented in Chapter 5 provides soil load estimates that were omitted from the data.

It is necessary to consider the permanent and temporary soil loads when a structure must be lifted.

Permanent Soil Load on Footing Toe: Table 8 can be used to estimate the permanent soil load on the footing toes. There are 8 inches of footing toe inside and outside of the stem wall that will carry a permanent soil load. The soil height is assumed to be 2-1/2 feet above the top of the footing. Referring to Table 8, notice that there is no weight provided for a soil height of 2-1/2 feet. One solution is to use the permanent soil load for 2 feet and then add an additional load for 1/2 foot. Looking at the portion of Table 8 below, the weight for two feet of soil per inch of footing toe is 18 lb/in. To estimate the additional weight of 1/2 foot of soil, it is necessary to divide the weight of 2 feet of soil by 4 to arrive at the weight of 1/2 foot of permanent soil load. An additional weight of 4-1/2 lb/in of toe is the result of this calculation. Therefore, the estimated permanent soil load per inch of footing toe is 22-1/2 lb/in.

Permanent soil load on footing toes:

22.5 lb/ft x 8 inches x 2 toes = 360 lb/ft

Table 8.	Estimated Soil Loads on Footings						
Permanent Soil Load on a Footing Toe – W_d							
Soil Height Against Wall	**2'**	4'	6'	7'	8'	9'	10'
Soil Load per inch of Footing Width	**18 lb**	37 lb	55 lb	64 lb	73 lb	83 lb	92 lb
To determine the permanent soil load on a footing toe, multiply the actual width of the footing toe (in inches) by the unit weight shown above for the soil height against the wall.							

Adjusted Working Load ($P_{W\text{-}Adj}$)

$P_{W\text{-}Adj} = DL + LL + W_d$

Side 1 – $P_{W\text{-}Adj\,1} = 9{,}600 + 360$ lb/lin.ft
$P_{W\text{-}Adj\,1} =$ **9,960 lb/ lin. ft**

Side 2 – $P_{W\text{-}Adj\,2} = 6{,}500 + 360$ lb/lin. ft
$P_{W\text{-}Adj\,2} =$ **6,860 lb/lin.ft**

Temporary (Lifting) Soil Load:
In addition to the permanent soil load, lifting will include raising a temporary soil load that is resting against the stem wall (inside and outside). Table 8, Graph 1, Chapter 5 (shown below), suggests that the 2-1/2 foot temporary soil load is approximately 490 lb/ft or 980 lb/ft total.

Estimated Actual Lifting Loads (P_L) = Adj. Working Load + Temp. Soil Load

$P_L = P_{W\text{-}Adj\,1} + W_t$

$P_{L\text{-}Pier\ Side\ 1} =$ **9,960 + 980 = <u>10,940 lb/ft</u>**

$P_{L\text{-}Pier\ Side\ 2} =$ **6,860 + 980 = <u>7,840 lb/ft</u>**

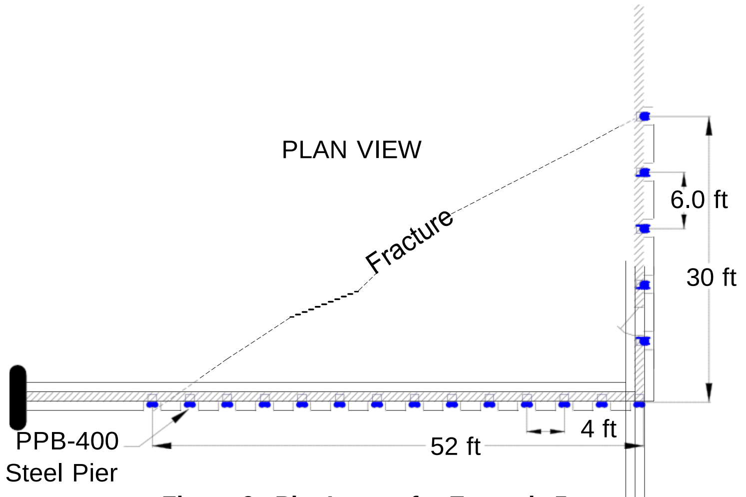
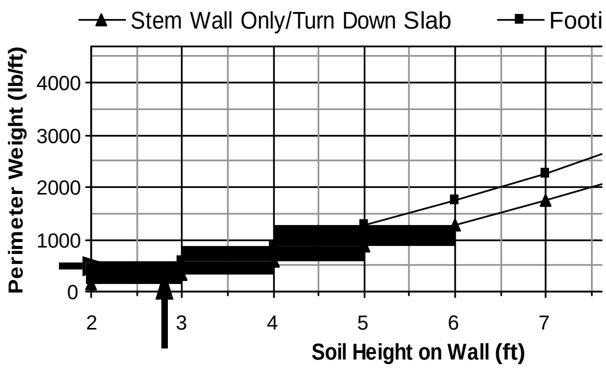


Figure 9. Pier Layout for Example 5.

Table 8. Estimated Soil Loads on Footings

Graph 1. Temporary Soil Load (One Side) – W_t



3. Select the Steel Pier System for the project:
The engineer specified a <u>minimum</u> factor of safety of 2.0 is required. Referring to the pier *Recommended Design / Service Load Ratings* on Table 1 in Chapter 5, the PPB-400 Steel Pier™ system was selected because it has a maximum "Safe Use" service load rating of 49,500 lb. Although this system is slightly more expensive than the PPB-350, this system will use fewer placements and incur lower labor costs.

4. Determine the pier spacing requirements.
By using Equation 1 from Chapter 5, the maximum pier spacing, "X", can be determined:

The pier spacing for each side of the structure is now calculated using Equation 1 from Chapter 6:

Equation 1: Pier Spacing
"X" = P_{DSL} / P_L or P_{DSL} = "X" x P_L

Pier Spacing - "X" = P_{DSL} / P_L, Where,
"X" = Pier Spacing
P_{DSL} = 49,500 lb (Model 400 at 2.0 FS)
$P_{L\,1}$ = 10,940 lb/ lf (Side 1)
$P_{L\,2}$ = 7,840 lb/ lf (Side 2)

The pier spacing for each side of the structure is now calculated using Equation 1 from Chapter 6:

Pier Spacing = "X" = $P_{SU\ Des}$ / P_L

Side 1:
"X_1" = 49,500 lb/10,940 lb/lf = 4.52 ft
"X_1" = Specify 4 feet on center (Side 1)

Lifting Load on the Piers Side 1:
10,940 lb/ft x 4 ft = **<u>43,760 lb</u>**

Side 2:
"X_2" = 49,500 lb/7,840 lb/lf = 6.31ft
"X_2" = Specify 6.0 feet on center (Side 2)

Lifting Load on the Piers Side 2:
7,840 lb/ft x 6 ft = **<u>47,040 lb</u>**

5. Prepare a pier layout plan – See sketch above:
Piers along the lower side (heaviest load) are spaced 4 feet on center for a total of 14 placements along 52 lineal feet of foundation. This design places piers supports from the point of fracture up to, and including, the corner.

Piers on the right side (lighter load) are spaced at 6 feet on center for a total of 5 placements, which puts the first pier 6 feet up from the corner and the last pier at the foundation fracture.

Calculate the pier working loads:

$P_{W\text{-}Pier\ Side\ 1} = P_{W\text{-}Adj\text{-}1}$ x 4 ft = **9,960 x 4 = <u>38,840 lb</u>**

$P_{W\text{-}Pier\ Side\ 2} = P_{W\text{-}Adj\text{-}2}$ x 6 ft = **6,860 x 6 = <u>41,160 lb</u>**

A total of 19 PPB-400 ECP Steel Piers™ are proposed to support the structure and restore lost elevation. This design provides a continuous service load of approximately 38,840 pounds per pier on the heavy

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side at the bottom of the sketch, and provides continuous service load support of approximately 41,160 pounds per pier placement on the lighter side at the right side of the sketch.

The calculated working load values include the design live and dead loads provided by the engineer along with the permanent soil loads on the footing toes added.

6. Determine the Service Load and Lifting Force Factor of Safeties for the Steel Pier Design:

The *ECP Pier System Load Ratings*" on Table 1 in Chapter 5 for the PPB-400 Steel Pier™ system states that the "Safe Use" *Recommended Design / Service Load* rating is 49,500 pounds and the *Ultimate-Limit Mechanical System Capacity* is 99,000 pounds. This capacity is divided by the Service Loads determined in Step 6.

Factor of Safety = Ult. Capacity/Service Load

F.S.$_1$ = 99,000/38,840 = **2.5** (Side 1 - Working)

F.S.$_2$ = 99,000/41,160 = **2.4** (Side 2 - Working)

The factor of safety for lifting the structure can also be calculated:

This design satisfies the engineer's minimum factor of safety = 2.0, and also insures that there will be sufficient pier capacity to break the footing loose from the soil and lift the temporary soil load without exceeding "Safe Use" design. Divide the *Ultimate-Limit Mechanical System Capacity* by the Lifting Load determined in Step 4.

Factor of Safety = Ult. Capacity/Lifting Load

F.S.$_{L1}$ = 99,000/43,760 = **2.26** (Side 1- Lift)

F.S.$_{L2}$ = 99,000/47,040 = **2.10** (Side 2 – Lift)

7. Determine Field Proof Test Force Requirement for the Piers:

The design calls for the piers to support a maximum continuous working load of up to 41,160 pounds (From Step 6 – Side 2 Load). According to ECP guidelines, it is recommended to perform a proof test of each pile once the pile reaches firm bearing. The ECP field proof test loading recommendation is to load the pier to 1-1/2 times the anticipated working load or until slight lifting of the foundation is observed.

Proof Load = Working Load x 1.5

P_T = 41,160 lb x 1.5 = 61,740 lb

(Use Max. 62,000 lbs. for Proof Test)

Estimating Driving Cylinder Pressure:

It is a good idea to calculate the estimated hydraulic pressure that will provide the required test load on the pier, and an estimate of the hydraulic pressure requirement to recover the lost elevation while all of the project requirements and design data are at hand. This is valuable information for the field technicians.

The ECP HYD-350-DC Drive Cylinder has a piston area of 8.29 in^2 as stated in *Pier Installation, Load Testing & Project Documentation* in Chapter 5. To determine the pressure on the drive cylinder to produce the Proof Load of 62,000 pounds, Equation 2 is used:

Equation 2:	**Hydraulic Cylinder Force** $\mathbf{F_{Cyl} = A_{cyl} \times P_{cyl}}$

Where: F_{Cyl} = Cylinder force on pier = 62,000 lb

P_{cyl} = Hydraulic Pressure, psi

A_{cyl} = Effective Cylinder Area = 8.29 in^2
(HYD-350-DC Cylinder = 8.29 in^2)

Change Equation 2 to solve for the cylinder pressure:

$\mathbf{P_{cyl} = F_{Cyl} / A_{cyl}}$ = 62,000 lb / 8.29 in^2

$\mathbf{P_{cyl}}$ = 7,479 psi **– <u>Use 7,500 psi</u>**

Estimating Lifting Cylinder Pressures:

The necessary hydraulic pressure on the HYD-254 Lifting Ram that is sufficient to raise the structure is determined in a similar manner.

$\mathbf{P_{cyl} = F_{Cyl} / A_{cyl}}$

Where: F_{Cyl} = Max. lift force on pier:
Side 1: 43,760 lb
Side 2: 47,040 lb

P_{cyl} = Hydraulic Pressure -- psi

A_{cyl} = Effective Cylinder Area – 5.16 in^2
(HYD-254 Ram Area = 5.16 in^2)

Side 1: $\mathbf{P_{cyl}}$ = 43,760 lb / 5.16 in^2 = 8,480
$\mathbf{P_{cyl}}$ = **<u>8,500 psi</u>**

Side 2: $\mathbf{P_{cyl}}$ = 47,040 lb / 5.16 in^2 = 9,125
$\mathbf{P_{cyl}}$ = **<u>9,100 psi</u>**

The Proof Test pressure and the estimates for Lifting Cylinder Pressures shall be supplied to the field personnel to assist with the installation.

END DESIGN EXAMPLE 5

Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to design using ECP Steel Piers™, installation procedures, load testing, and documentation of each pier placement. If you have questions about structural weights, product selection or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call us at 913 393-0007, Fax at 913 393-0008.

Design Example 5A – Estimate the Drive Cylinder and Lifting Ram Pressures
“Quick and Rough” Method for Design Example 5

“Quick and Rough” estimating can also determine the cylinder pressures required to “Proof Test” the piers and to determine the anticipated lifting pressure for restoration of the structure. Use Graph 4 from Chapter 5. (Reproduced below)

1. Begin by locating the Proof Test load requirement of 62,000 pounds at the left edge of the graph.

2. Read horizontally to the right until encountering the solid line (HYD-350-DC Cylinder). Read to the down to determine the Drive Cylinder pressure requirement.

P_{Cyl} = <u>7,500 psi.</u>

Similarly, the anticipated maximum pressure on the HYD-254 Lifting Ram is determined:

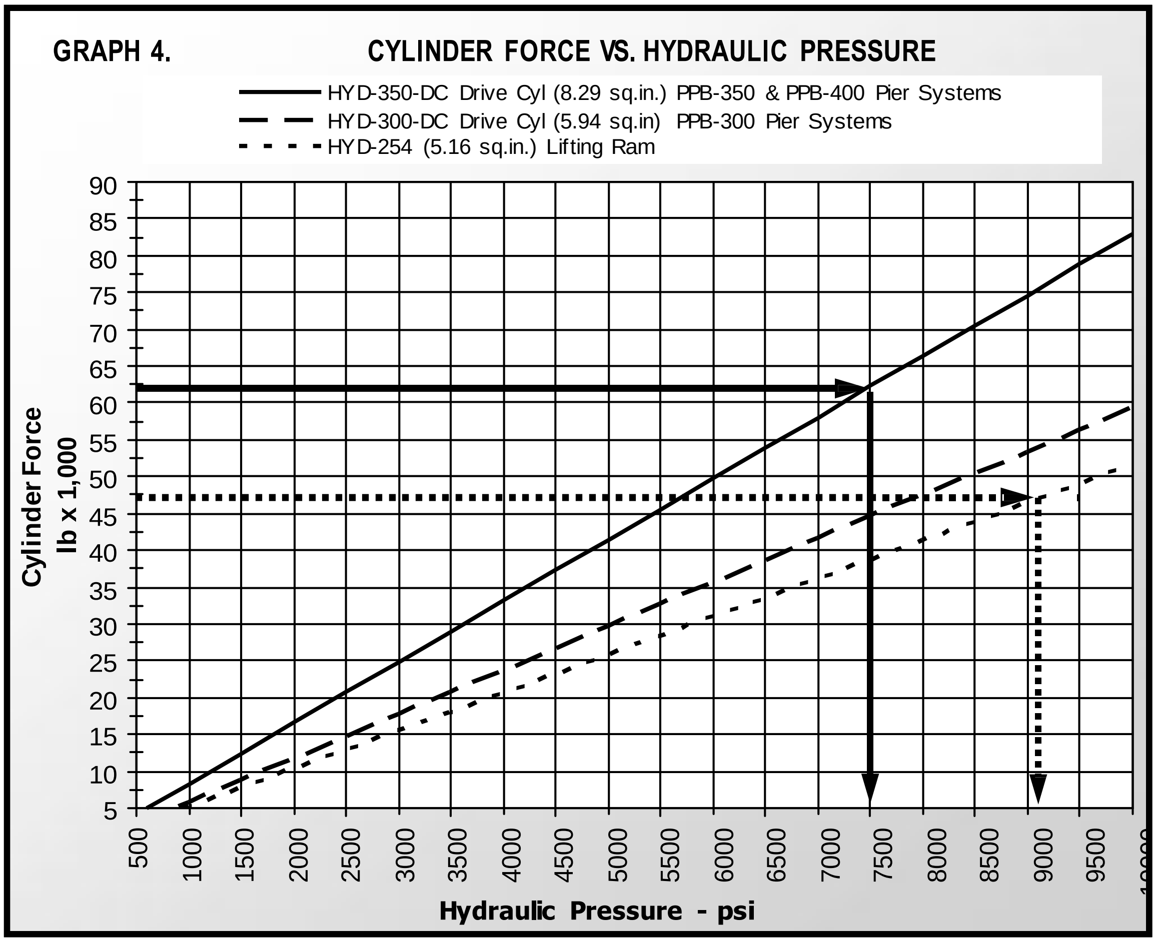
1. Begin by locating the proof test load requirement of 47,088 pounds at the left edge of the graph.

2. Read horizontally to the right until encountering the short dashed line (HYD-254 Lifting Ram). Read to the down to determine the estimated maximum pressure requirement.

P_{Cyl} = <u>9,100 psi.</u>

This information shall be supplied to the field personnel to assist with the installation.

END DESIGN EXAMPLE 5A



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Design Example 6 – Determining Force Applied to Pier from Field Data

For this example it is assumed that the technician in his field report states a driving pressure on a PPB-300-EPS pier pipe of 5,500 psi. The actual installation force on the pier pipe can be determined and submitted to the engineer.

Use Equation 2 from Chapter 5 to determine the downward force on the pier pipe:

Equation 2:	**Hydraulic Cylinder Force**
	$\mathbf{F_{Cyl} = A_{cyl} \times P_{cyl}}$

Where:

F_{Cyl} = Cylinder force on pier –lb
P_{cyl} = Hydraulic Pressure – 5,500 psi
A_{cyl} = Effective Cylinder Area – 5.94 in^2
(HYD-300-DC Cylinder = 5.94 in^2)

$\mathbf{F_{Cyl}}$ = 5.94 in^2 x 5,500 lb/in^2

$\mathbf{F_{Cyl}}$ = **<u>32,670 lb.</u>**

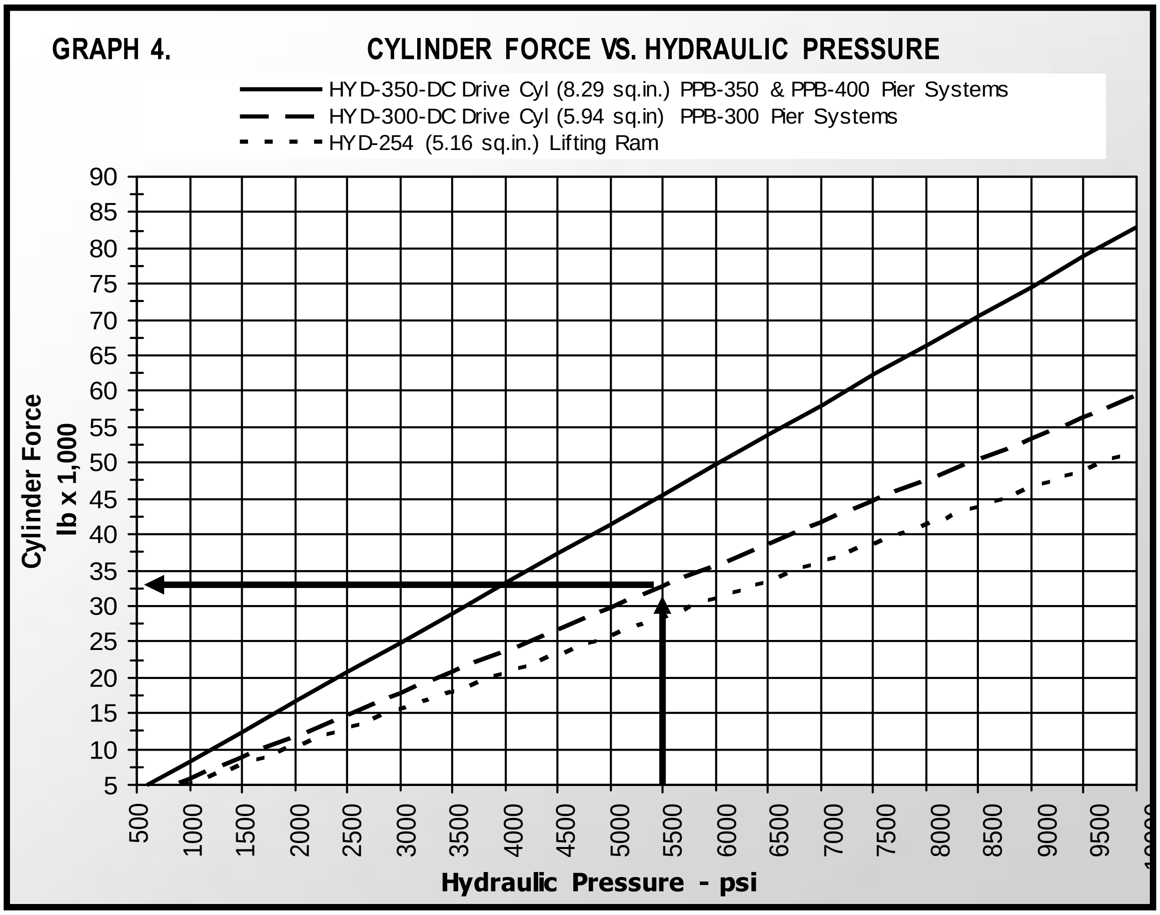
Design Example 6A – Determining Force Applied to Pier - "Quick and Rough" Method

"Quick and Rough" estimating can also determine the force on the pier when the cylinder pressure is known. Use Graph 4 from Chapter 5. (Reproduced below)

1. Begin by locating "5,500 psi" the pressure on the cylinder on the lower edge of the graph.
2. Read upward from the bottom of the graph until encountering the line with long dashes (HYD-300-DC Drive Cylinder). Read to the left to determine the force on the pier.

$\mathbf{F_{Cyl}}$ = **33,000 lb.**

END DESIGN EXAMPLE 6



Review of Results of Example 5A, 6 & 6A

The result obtained by the "Quick and Rough" analysis on these examples show that it is possible to obtain results very quickly that are relatively accurate. It is important to accurately lay out the lines on the graph to obtain best results. The "Quick and Rough" method returned useful results without requiring mathematical calculations.